Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of

Use of Spectrum Bands Above 24 GHz For Mobile Radio Services	)))	GN Docket No. 14-177
Emission Limits for the 24.25-27.5 GHz Band	))	ET Docket No. 21-186

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I. Summary

The FCC *Public Notice* of April 26, 2021[1] proposes that the Commission implement in its rules the terms of WRC-19 Res. 750 for out-of-band emission (OOBE) limits on 5G usage in the 24.25-27.5 GHz band in order to protect critical environmental satellites in the nearby 23.6-24.0 GHz band which has strict protection under both ITU Radio Regulation 5.340 and US Allocation Table footnote US246. We fully agree with this protection goal and the adequacy of the proposed limits from Res. 750 to achieve the intended protection goal and urge the Commission to adopt such limits.

However, there may be other more efficient ways to achieve the same protection goals while achieving more cost-effective use of the 24 GHz 5G band and the proposed terms discourage capital formation for R&D on such technology by focusing only on limits denominated in Total Radiated Power (TRP) which is convenient to measure for today's MIMO technology but is not directly correlated with the interference threat to the critical satellites that much be protected. Thus

[1] https://docs.fcc.gov/public/attachments/DA-21-482A1.pdf

we urge the Commission to state that it will welcome waiver requests for alternative antenna technologies that demonstrate that the resulting emissions will protect the passive satellites to the limits stated in the noncontroversial Recommendation ITU-R RS.2017-0.[2] Further we ask the Commission to seek comment on an alternative limit that is modeled on the structure used by its UK counterpart Ofcom for protection of similar passive satellites above 100 GHz from terrestrial spectrum users. While today's commercially available MIMO systems do not *directly* try to limit OOBE levels at above horizon elevation angles that threaten passive satellites, future generations could if they had the regulatory flexibility to do so. Having such alternatives could encourage R&D on such technology by clarifying the regulatory standards that would apply, thus decreasing regulatory risk for such developers while guaranteeing satellite protection. The proposal in the Notice uses TRP as the only metric for determining compliance with 23.6-24 GHz passive satellite protection. This will deter development of other protect passive satellites approaches that could lead to more favorable 5G implementation in some locations. If this decision is viewed as a precedent for passive satellite protection regulation in other bands it will *be more harmful* since in higher bands that path loss from terrestrial transmitters to passive satellite varies greatly with *both* frequency elevation angle and there are major possible benefits if a more <u>direct measure</u> of terrestrial transmitter power that could actually reach a passive satellite could be the basis of a protection goal.

II. Author(s)

Information about the authors of these comments is contained in Attachment I. These comments reflect the views of the authors and are not necessarily the viewpoint of Northeastern University. Neither of the authors have a financial interest in these proceedings and are submitting

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[2] Recommendation ITU-R RS.2017-0 (08/2012) (https://www.itu.int/dms_pubrec/itu-r/rec/rs/R-REC-RS.2017-0-201208-I!!PDF-E.pdf)

these comments in the public interest.

III. Introduction

The OOBE limits in these proposals were adopted by WRC-19 Resolution 750/Res.750 and were made applicable to the 22.55-23.55 GHz and 24.25-27.5 GHz by ITU Radio Regulation 5.338A[3] which is codified in the 2020 edition of the Radio Regulations.[4] Although Res. 750 gives the numerical values of the limit, there is no explanation there of how these were derived or what the assumptions were. It appears that these limits were based on analyses of the former ITU-R Task Group 5/1 and are documented in Annex 3 to Task Group 5/1 Chairman's Report dated September 19, 2018[5] and in several of its attachments. While these documents are on the ITU's voluminous website, they are not publicly available. Thus, the Notice does not describe the limitations of the assumptions that went into the proposed limits nor does it ask comment on the scope of their validity.

The proposed limits are stated in terms of TRP and the definition of TRP is given in fn. 5 of Res. 750:

> "The TRP is to be understood here as the integral of the power transmitted from all antenna elements in different directions over the entire radiation sphere."

An equivalent description of TRP that is easier to understand involves surrounding the antenna with an inflated balloon that has a lining of a conductive material and measuring the rate at which the balloon's surface heats up. This measures the total power leaving the antenna in

[3] "**5.338A** In the frequency bands 1 350-1 400 MHz, 1 427-1 452 MHz, 22.55-23.55 GHz, 24.25-27.5 GHz, 30- 31.3 GHz, 49.7-50.2 GHz, 50.4-50.9 GHz, 51.4-52.4 GHz, 52.4-52.6 GHz, 81-86 GHz and 92-94 GHz, Resolution 750 (Rev.WRC-19) applies."

[4] https://www.itu.int/pub/R-REG-RR-2020

[5] https://www.itu.int/md/R15-TG5.1-C-0478/en (Access to the documents enumerated here all require an ITU TIES for access. Americans can request such accounts from FCC and State Department if they are involved in ITU-R activities. Access is also available to entities that join ITU. *See* https://www.itu.int/en/myitu/Membership/Become-a-Member

every direction over a hypothetical sphere surrounding the antenna. MIMO systems consist of multielement antennas, somewhat like military phased array antennas, where the power and phase of each element is adjected by a controller to maximize the signal strengths received at the intended destination(s). While in many MIMO systems the RF power is generated external to the antenna and the antenna components only attenuate and phase shift/delay the RF signal, that is not a fundamental requirement of MIMO technology.

The sky is clearly not an intended destination for 5G transmitted power and any radiation skyward is the inevitable unintended byproduct of antennas with finite size.[6] The effective radiated power at such positive elevation angles is not directly controlled by today's commercially available MIMO technology so the format of OOBE limits in today's §22.359[7] is not directly applicable for protecting passive satellites in nearby bands. Today, TRP is widely used in the cellular industry as a metric for MIMO system performance and thus preferred by that industry as an approach to quantify radiated power with available MIMO technology and testing systems. <u>TRP was not developed as a tool for quantifying interservice interference threats.</u> TRP is not directly relative to the interference threat to passive satellites because it includes emissions over the whole sphere, most of which have no potential of reaching such satellites. However, with today's commercially available MIMO system models and <u>with appropriate assumptions</u> the stated limits will protect the passive satellites adequately.

Unfortunately, Res. 750 does not state how these limits were computed to assure compliance with the protection terms of RS.2017. That computation must have included an unstated assumption of what fraction of the TRP from today's standard MIMO systems would

[6] Most of the power from 5G transmitters that could potentially reach a passive satellite is from radiation at positive elevation angles. There is the possibility of power from negative elevation angles being reflected and scattered skyward by objects near the transmitter but that is a lesser problem.
[7] 47 C.F.R. §22.359

actually be a threat to the satellites. These assumptions were likely based on the present specific MIMO technology designs that today's large multinational equipment suppliers intend to sell to the world market as standard products and do not represent alternative designs which might be applicable to the US market and to innovative US developers who may be more focused on the US situation rather than the worldwide market.[8]

Such assumptions are also not necessarily applicable to future MIMO-like antenna array designs, particularly if the designers *explicitly* seek to minimize radiation in directions that are of no benefit to the 5G system and are an interference threat to the passive satellites. We believe the Commission's policies should be flexible enough to encourage such new technology under the terms of §7 of the Communications Act of 1934, as amended, which states "It shall be the policy of the United States to encourage the provision of new technologies and services to the public".[9]

Under the terms of RR5.338A, the limits in Res. 750 become binding on US entities if the USA either ratifies the Final Acts of WRC-19 or decides to agree to comply with them.[10] However, the longstanding terms of RR4.4[11] give the Commission the options of taking an alternative approach if it decides that such an approach will

> "not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the (ITU) Constitution, the (ITU)

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[8] While the US allocations near 24 GHz are *consistent* with the ITU International Allocations in the Radio Regulations, they are not the *same*. For example, in 24.65-24.75 GHz there is an ITU Region I allocation for coprimary FIXED-SATELLITE (Earth-to-space) that has no equivalent Region II or US allocation. A multinational supplier with products for a worldwide market may wish to sell only products that protect the allocation even though it is not necessary in the US market and systems lacking that protection may have advantages in some application cases in the US in lower population density areas.

[9] 47 U.S.C. §157

[10] In recent decades, US like many other countries has not *ratified* WRC outcomes but has made "Approval Ipso Facto" https://www.itu.int/online/mm/scripts/gensel25?agrmtid=0000925267

[11] "**4.4** Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations."

Convention and these Regulations."

Thus, an ITU member such as the US can choose to allow a different standard for protecting passive satellites in 23.6-24.0 GHz for some installations if it decides that such a standard would not cause harmful interference. For example, FCC could do so under its longstanding waiver provisions in §1.925[12] if it finds

> (i) The underlying purpose of the rule(s) would not be served or would be frustrated by application to the instant case, and that a grant of the requested waiver would be in the public interest; or
>
> (ii) In view of unique or unusual factual circumstances of the instant case, application of the rule(s) would be inequitable, unduly burdensome or contrary to the public interest, or the applicant has no reasonable alternative.

Absolute compliance to the specific terms of Res. 750 and RR5.338A would mean that alternative technologies to protect passive satellites could not be implemented without a change to these ITU provisions by a future World Radio Conference. As these conferences are held every 4 years and general terms of the agenda for such conferences have to be decided at the previous conference, the time lead necessary to adopt such a change is in the 6-8 year range.

IV. Benefits of Such a Change

While the OOBE TRP levels in Res. 750 and the FCC proposal were calculated based on assumptions of how much of that power would be transmitted into the sky where it might adversely impact passive satellites, the fraction of TRP that is transmitted at such positive elevation angles is not a physical constant but rather is a function of the MIMO antenna design and its parameters. Usually, MIMO systems adjust the phase and amplitude at each of the antenna elements to maximize the power transfer to the transmitters to the receiver. It is possible to design the antenna controller to compromise between such maximization and also limiting the power that is transmits into the sky at positive elevation angles. This is illustrated in Figure 1.

[12] 47 C.F.R. §1.925

Both antennas have the same TRP. Because the antenna with more elements has much lower transmitted power skyward, the TRP could be increased beyond the Res. 750 limit while protecting the passive satellites to the fundamental RS.2017 interference limit – the basic objective of Res. 750. In the base of base stations, increasing the TRP in the antenna with more elements case would then give such base stations greater range and thus decrease the infrastructure cost for 5G in areas with lower user density – although this depends on the final cost increase due to the increased number of elements.

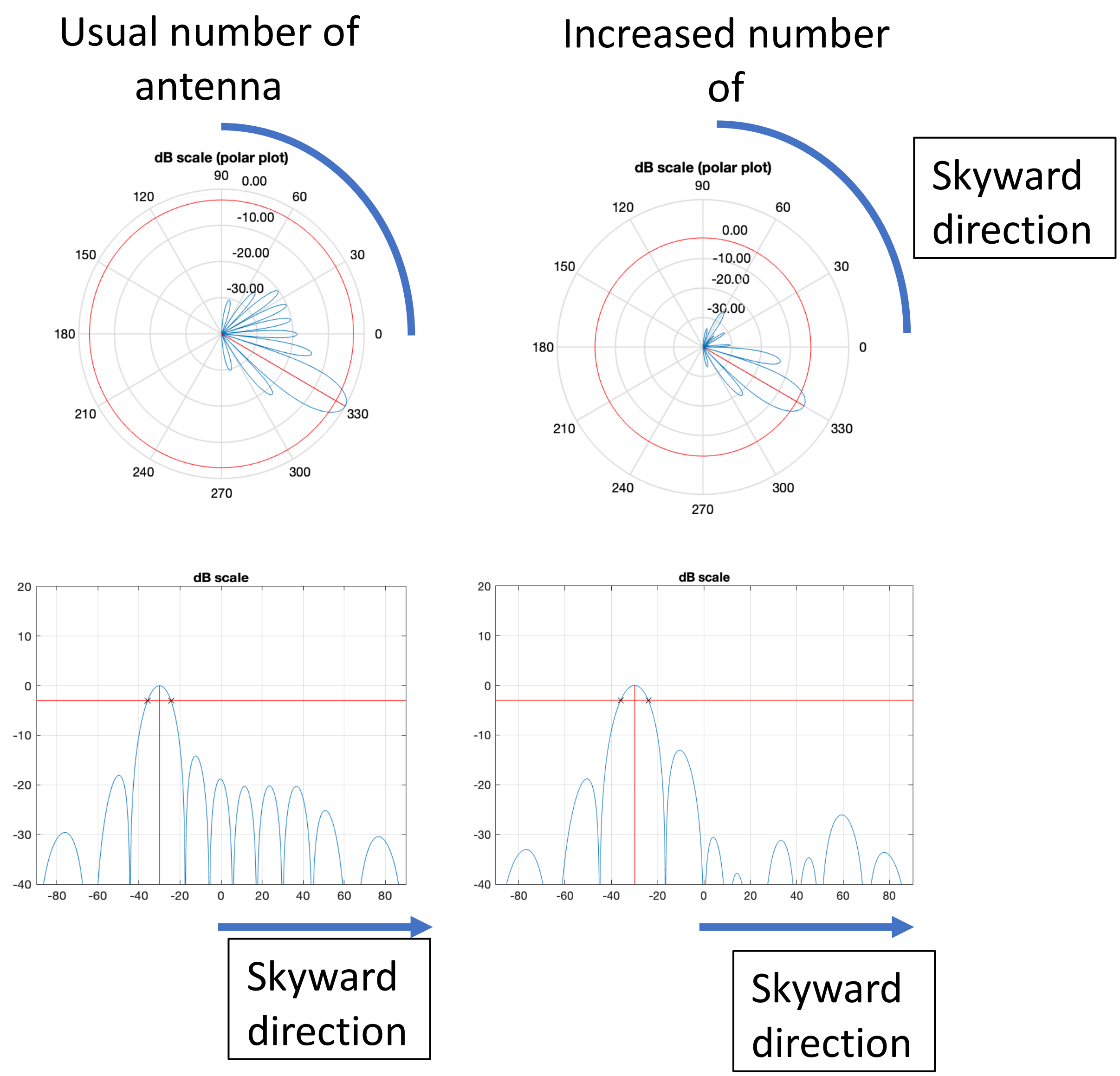

Figure 1: Impact of increased number of antenna elements and modified MIMO controller on power transmitted above the horizon (Arjun Singh – Northeastern University)

In general, to maintain system performance such a MIMO antenna would need more antenna elements and thus have higher cost than a traditional MIMO antenna that did not attempt to control high elevation angle power. This in turn would increase the cost of such antennas.

In many locations with 5G high user density the increased performance with its increase cost would have no advantage. But in areas with lower user density such as suburbs and rural areas it would have real advantages in that high transmitter power at the low elevation angles corresponding to most 5G users in such areas, compared to a Res. 750 TRP limit compliant design, would give a larger coverage area and thus decrease the number of 5G 24 GHz base stations needed. Thus the infrastructure cost/user may be less in such areas if there was an interference-based alternative to meeting the proposed pure TRP limit and this may encourage buildout of 24 GHz 5G in such areas.

At present, most of the US 24 GHz 5G licenses are owned by a foreign-owned carrier with operations in many countries. We believe the present views of such a licensee should not be determinative in view of the commitment to ITU-based transmitter power/TRP regulation that would be implied by the present proposal in its pure form and the resulting commitment to the ITU forum with its multiyear delays to update the power levels in view of any new technology.

V. Proposed Alternatives to Codifying Only Res. 750 TRP Limits

We give below three alternatives for the Commission's consideration to supplement the proposed implementation of the Res. 750 TRP limits

A. Waiver approach

We ask that the Commission explicitly states in its adoption of any rules in the proceeding that its regulatory goal is the protection of passive satellites protected by RR5.340 and US246 and that meeting the stated TRP limits is an acceptable way to show such compliance, but not necessarily the only way to do so. Thus the Commission should explicitly cite the terms of §§1.3, 1.925[13] of its rules to encourage waiver requests for alternative showing that innovative technologies can assure protection of the passive satellites to the RS.2017 levels that are the explicit goals of Res. 750.

B. Ofcom elevation mask approach

The Commission's UK counterpart, Ofcom, has developed a different approach that it has used for protection of passive satellites for terrestrial transmitters sharing certain bands above 100 GHz.[14] Table 1 below is copied from its decision:

Figure 6.1: 'Spectrum Access: EHF' licence technical requirements

	Power limits (*max EIRP in dBm*) and emissions restrictions on outdoor use		
USE	**116-122 GHz**	**174.8-182 GHz**	**185-190 GHz**
Indoor	55	55	55
Outdoor	55	55	55
For outdoor use, EIRP at angles (degrees°) relative to main beam in the elevation plane shall not exceed:			
	13 at > 10° 1 at > 40° -3 at > 60°	13 at > 10° 1 at > 40° -3 at > 60°	25 at > 10° 14 at > 40° 10 at > 60°
When devices are used outdoors, the main beam elevation angle of licensed devices shall not exceed 20° above horizontal.			

Table 1: Ofcom criteria for protecting 3 passive bands above 100 GHz

In this approach Ofcom gives a maximum main beam elevation angle and then gives upper EIRP limits for 3 different ranges of elevation angles. Standard MIMO technology today can not guarantee that these limits are met since MIMO antenna controllers are designed to adjust antenna elements' power and phase to maximize power at intended receivers in a multipath environment. But if the number of elements is increased somewhat controllers can be developed that address **both** the maximum power at intended receivers **and** meeting designated EIRP

[13] 47 C.F.R. §§1.3, 1.925

[14] Ofcom, Supporting innovation in the 100-200 GHz range: Increasing access to Extremely High Frequency (EHF) spectrum, 1 October 2020 (https://www.ofcom.org.uk/__data/assets/pdf_file/0024/203829/100-ghz-statement.pdf)

limits. Such antenna systems would likely be more expensive than today's MIMO systems, at least initially. But they would also have higher powers in the low and negative elevation angles that are most needed by 5G systems and hence could have larger coverage areas and fewer base stations needed.

C. Dynamic protection in cases where passive satellite orbits are known

There is no present ITU regulatory requirement that passive satellites be registered in a public data base although ITU and WMO both have public databases that list many passive satellites from a wide range of countries. The protection granted by the present terms of RR5.340 does not appear to be preconditioned on such registration. It is unclear at present if all the passive satellites in the 23.6-24.0 GHz band have orbits that are publicly known but if it is determined that they are and that such information will continue to be available in the future then another protection option is possible.

If all orbit parameters of all satellites in the 23.6-24.0 band are known and the maximum number of satellites possibly in the view of a 5G antenna is limited, passive satellites can be protected by having each 5G emitter place a null on the satellite orbit positions' elevation angle and azimuth as they are within view of the 5G antenna. While this may not be practical for mobile units, it is much likelier to be practical for base stations and could be a desirable option to the maximum TRP limit of Res. 750.

VI. TRP Measurement Issues

The *Notice* lacks any specific statement of how TRP is measured and gives no indication about how this missing information will be developed and adopted. It only cites fn. 5 of Res. 750 which states "TRP is to be understood here as the integral of the power transmitted from all antenna elements in different directions over the entire radiation sphere." This is a theoretical concept that is impractical so actual measurement must use *some* approximations. A recent conference paper[15] describes the special case of measuring TRP for the case of GSM handsets. For this handset example the paper gives results from three different measurement approaches:

- Scattered Field Measurement (SFM) method,
- Stirred-Mode Chamber (SMC) method and
- 3-D Pattern Integration Method (3-D PIM)

The 3 approaches give differing results as they are all approximations to a theoretical concept. While many MIMO designs have constant theoretical TRP independent of the multipath environment in which they are used, this independence can not be assumed in general and should not be made a *de facto* or *de jure* long term requirement for 24 GHz transmitters.

In the case of MIMO systems in handsets, a "phantom" simulating a human head is needed as the MIMO controller's behavior in directing the power depends on any objects nearby that absorb or reflect the RF power – in this case the user's head. Thus, in addition to the measurement strategies listed above, as well as possible other ones, any FCC TRP regulation must be coupled with at least an incorporation by reference of a detailed TRP measurement procedure specifying the type of phantom head, the location of the phantom head with respect to the transmitter, and how measurements are to be taken. FCC cannot simply delegate this measurement procedure development to ITU or a nongovernmental standards body such as 3GPP[16] although it could choose to incorporate them by reference through notice and comment once that are adopted by such an entity.

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[15] J. Krogerus, K. Kiesi and V. Santomaa, "Evaluation of three methods for measuring total radiated power of handset antennas," *IMTC 2001. Proceedings of the 18th IEEE Instrumentation and Measurement Technology Conference. Rediscovering Measurement in the Age of Informatics (Cat. No.01CH 37188)*, 2001, pp. 1005-1010 vol.2, (doi: 10.1109/IMTC.2001.928231.)

[16] 1 C.F.R. §51.1,11

VII. Summary

We have shown that adoption of the Res. 750 TRP limit as the only permissible way to for 24 GHz 5G transmitters to protect the nearby passive satellite band is a *sufficient* way to achieve such protection but is not a *necessary* restriction. FCC should adopt that TRP limit but should leave the door open for alternative approaches that protect the passive satellites to the strict and noncontroversial ITU-R Recommendation RS.2017 limit and that do not require US developers and US carriers to participate in a 6-8 year World Radio Conference effort to allow use of new technology to enlarge their service areas in this band.

The adoption of the TRP-only limit would also set a poor precedent for other millimeterwave and terahertz bands that need both OOBE and inband limits to protect passive satellites. While it is critical to protect passive satellites from harmful interference, there needs to be done in a balanced way that is not unnecessarily restrictive in the long term to the communications users of spectrum and do not block alternative innovative technology for spectrum sharing. We note that for spectrum above 71 GHz, WRC-19 Res. 731[17] requires "to the

[17] https://www.itu.int/dms_pub/itu-r/oth/0C/0A/R0C0A00000F00149PDFE.pdf

extent practicable" that "the burden of sharing among active and passive services should be equitably distributed among the services to which allocations are made". While this does not apply to the 24 GHz spectrum in question in these proceedings but should be considered when expanding the scope of this type of regulation to higher bands.

/S/

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Attachment I: Author Information

Michael J. Marcus is a native of Boston and received S.B. and Sc.D. degrees in electrical engineering from MIT. Prior to joining the FCC in 1979, he worked at Bell Labs on the theory of telephone switching, served in the U.S. Air Force where he was involved in underground nuclear test detection research, and analyzed electronic warfare issues at the Institute for Defense Analyses.

At FCC his work focused on proposing and developing policies for cutting edge radio technologies such as spread spectrum/CDMA and millimeterwaves. Wi-Fi is one outcome of his early leadership. The total amount of spectrum he proposed for unlicensed use and directed the drafting of implementing rules is 8.234 GHz. He also participated in complex spectrum sharing policy formulation involving rulemakings such as ultrawideband and MVDDS. Awarded a Mike Mansfield Fellowship in 1997, he studied the Japanese language and spent a year at the FCC's Japanese counterpart. He retired from FCC in 2004 and has worked since them as an independent consultant specializing in innovative spectrum technologies.

He has taught electrical engineering courses at George Washington Ujiversoty, MIT, and Virginia Tech and is now an Adjunct Professor in Electrical & Computer Engineering and Principal Research Scientist, Institute for the Wireless Internet of Things at Northeastern University. He was recognized as a Fellow of the IEEE "for leadership in the development of spectrum management policies", received in 1994 IEEE-USA's first Electrotechnology Transfer Award, and received in 2013 the IEEE ComSoc Award for Public Service in the Field of Telecommunications "For pioneering spectrum policy initiatives that created modern unlicensed spectrum bands for applications that have changed our world."

Josep Miquel Jornet is an Associate Professor in the Department of Electrical and Computer Engineering, the director of the Ultrabroadband Nanonetworking (UN) Laboratory, and a member of the Institute for the Wireless Internet of Things and the SMART Center at Northeastern University (NU). He received a Degree in Telecommunication Engineering and a Master of Science in Information and Communication Technologies from Barcelona School of Telecommunications Engineering (ETSETB), Universitat Politècnica de Catalunya, Spain, in 2008. From September 2007 to December 2008, he was a visiting researcher at the Massachusetts Institute of Technology, Cambridge, under the MIT Sea Grant program. He received the Ph.D. degree in Electrical and Computer Engineering from the Georgia Institute of Technology, Atlanta, GA, in August 2013. Between August 2013 and August 2019, he was in the Department of Electrical Engineering at the University at Buffalo (UB), The State University of New York (SUNY).

His research interests are in Terahertz communication networks, wireless nano-bio-communication networks, and the Internet of Nano-Things. In these areas, he has co-authored more than 160 peer-reviewed scientific publications, including 2 book and 4 US patents. His work has received more than 10,000 citations (h-index of 45 as of June 2021). Since July 2016, he is the Editor-in-Chief of Elsevier’s Nano Communication Networks Journal. He is serving as the lead PI on multiple grants from U.S. federal agencies including the National Science Foundation, the Air Force Office of Scientific Research (AFOSR), and the Air Force Research Laboratory (AFRL). He received the National Science Foundation CAREER Award in 2019 and is the recipient of several other awards from IEEE, ACM, UB and NU.